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Root severance and trees – response to increasing levels of root removal

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Motivation for Research – a 1 size fits all “solution”

“No roots greater than 35 mm shall be severed and the severance of any root less than 35 mm shall be done at the discretion of the works arborist.”

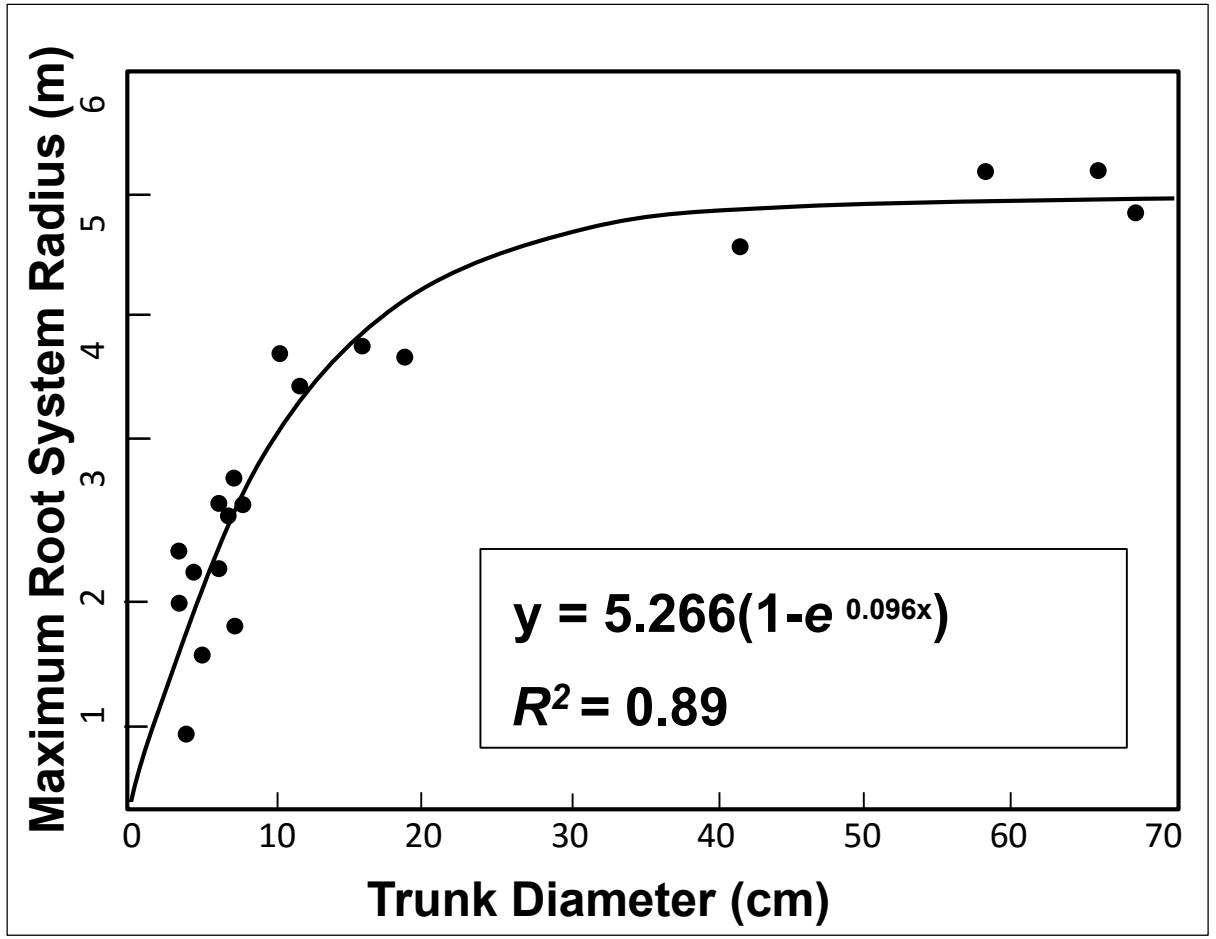
Managing Roots and Development

- Trees and infrastructure are in close proximity in cities
  - it's no surprise that conflicts arise
- Understanding root architecture informs decision making in situations where root severance is necessary
  - Road work
  - Trenching
  - Basement or foundation work

Photo credit: Kyle Daniel

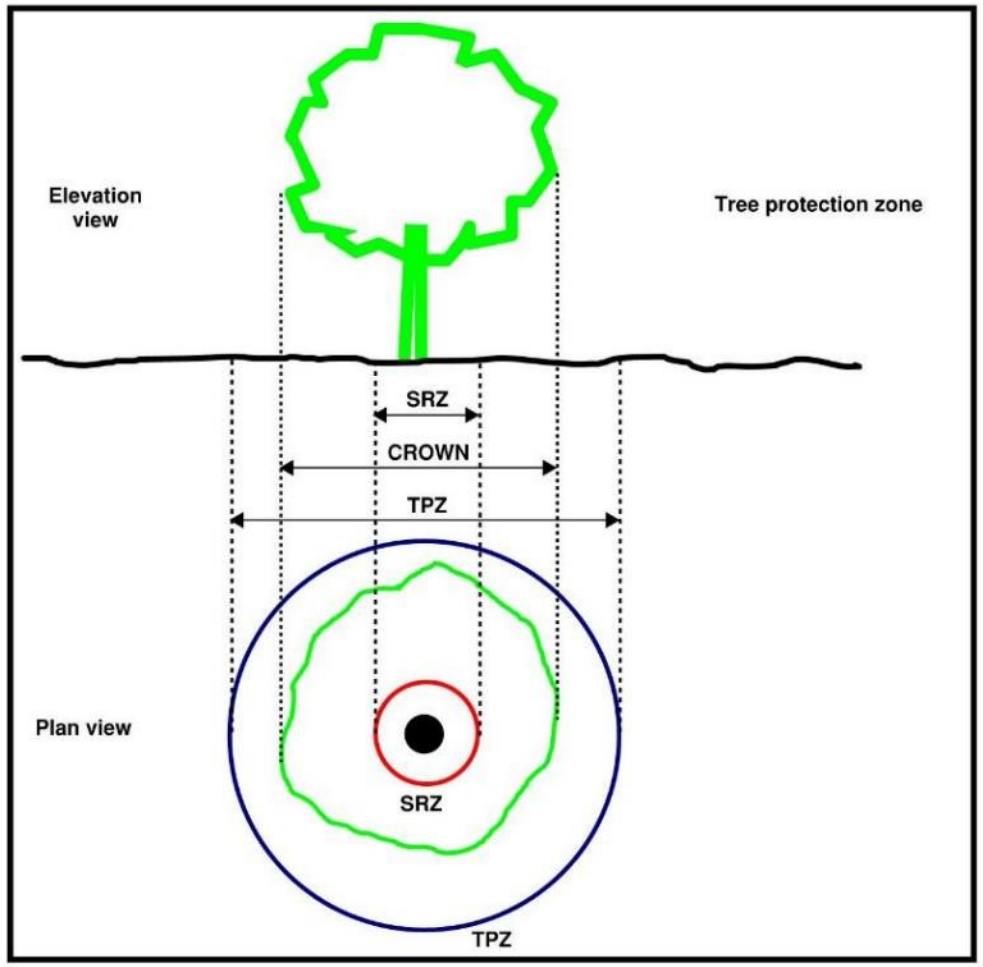
Root Architecture – Where are the roots?

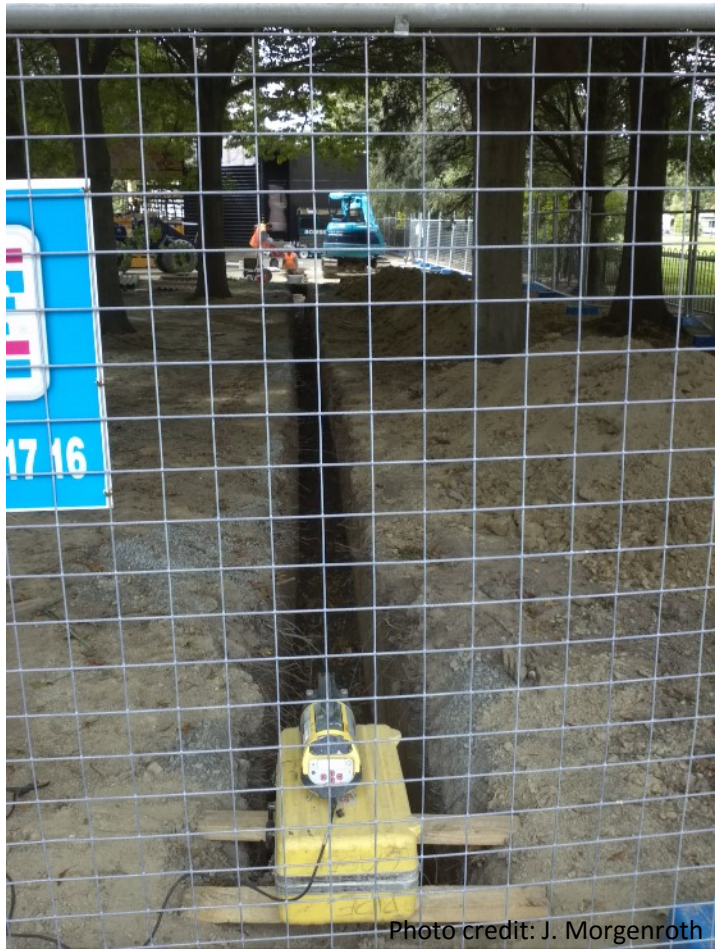
- Root system depth is variable, with a concentration of shallow roots, but extending > 2 m deep[1]
- Zone of rapid taper gives way to structural roots and fine roots
- Root system radius is strongly related to DBH[1]
  - Up to ~ 20 cm DBH, a 38:1 ratio for root spread to DBH is a good fit
  - Above this, the ratio decreases



1 - Day, S.D., P.E. Wiseman, S.B. Dickinson, and J.R. Harris. 2010. Contemporary concepts of root system architecture or urban trees. Arboriculture & Urban Forestry 36:149–159.

Best Practices for Managing Tree Roots





We develop Tree Protection Zone best practices to avoid poor outcomes

Differing Practices for Managing Tree Roots

Document	Region	Author	Tree Protection Zone (TPZ)	TPZ Equivalent DBH ratio	Root Diameter Threshold
BS5837:2005 Trees in relation to construction	United Kingdom	British Standards Institute (2005)	Circle of radius = 12 × DBH	12:1	25 mm
National Joint Utilities Group guidelines for the planning, installation and maintenance of utility apparatus in proximity to trees	United Kingdom	National Joint Utilities Group (2007)	Circle of radius = 4 × trunk circumference	12.57:1	25 mm
A guideline for tree and bush protection on development sites	New Zealand	NZArb (2011)	Circle of radius = 4 × trunk circumference	12.57:1	N/A
AS 4970-2009 Protection of Trees on Development Sites	Australia	Standards Australia (2009)	Circle of radius = 12 × DBH	12:1	N/A
Guidelines on Tree Preservation During Development	Hong Kong	The Government of Hong Kong (2015)	Drip line, tree height, or 6 – 18 × DBH	6:1 – 18:1	N/A
Construction Damage Assessments: Trees and Sites	USA	Coder, K.D. (1996)	Circle of radius = 1.25’ for every 1” of DBH	15:1	N/A
Arboriculture: integrated management of landscape trees, shrubs, and vines	USA	Harris, Clark and Matheny (2004)	6 - 18 × DBH	6:1 – 18:1	N/A

Reconciling BMPs with Research

- BMPs generally recommend a TPZ radius to DBH ratio of between 6:1 and 18:1
- Research has shown:
  - Root spread to DBH radius of up to 38:1 for urban trees
    - TPZ do not protect all roots, but
      - Review of the literature has shown growth and stability generally not impacted unless trenching is severe[2]
        - $< 3 \times$ DBH on more than 1 side
      - Review of the literature has shown functional responses (e.g. stomatal conductance, photosynthetic efficiency) exist and tend to increase with root severance intensity[3,4]
        - Effects of trenching/severance distance not well studied
- TPZs are likely effective in preventing most negative effects on function, growth, and stability

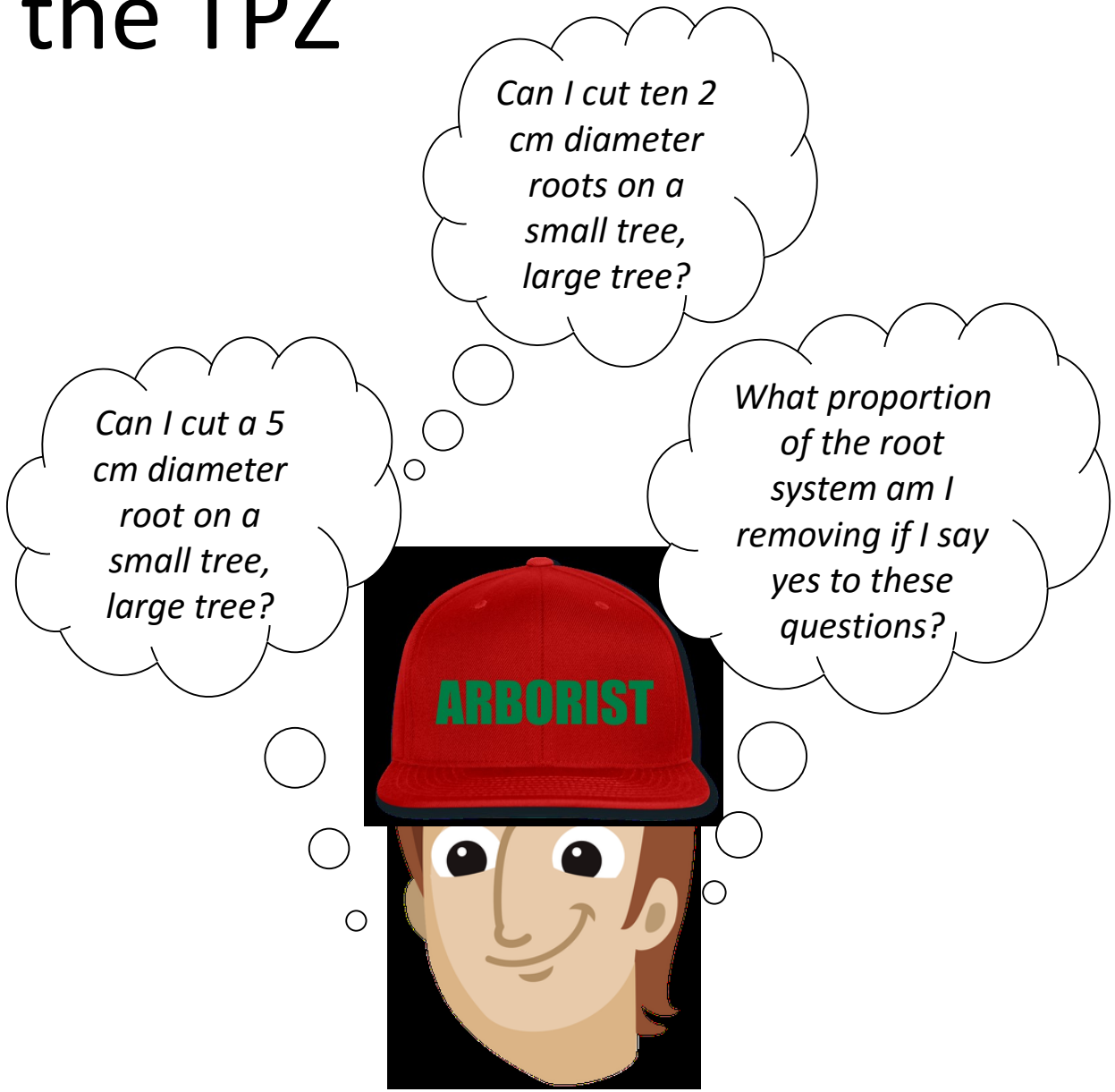
2 - Watson, G. W., Hewitt, A. M., Custic, M., & Lo, M. (2014). The Management of Tree Root Systems in Urban and Suburban Settings: A Review of Soil Influence on Root Growth. Arboriculture & Urban Forestry, 40(4): 249 – 271.

3 – Fini, A., Ferrini, F., Frangi, P., Piatti, R., & Amoroso, G. (2013). Effects of root severance by excavation on growth, physiology and uprooting resistance of two urban tree species. Acta horticulturae.

4 – Dong, T., Duan, B., Zhang, S., Korpelainen, H., Niinemets, Ü., & Li, C. (2016). Growth, biomass allocation and photosynthetic responses are related to intensity of root severance and soil moisture conditions in the plantation tree Cunninghamia lanceolata. *Tree physiology*, *36*(7), 807-817.

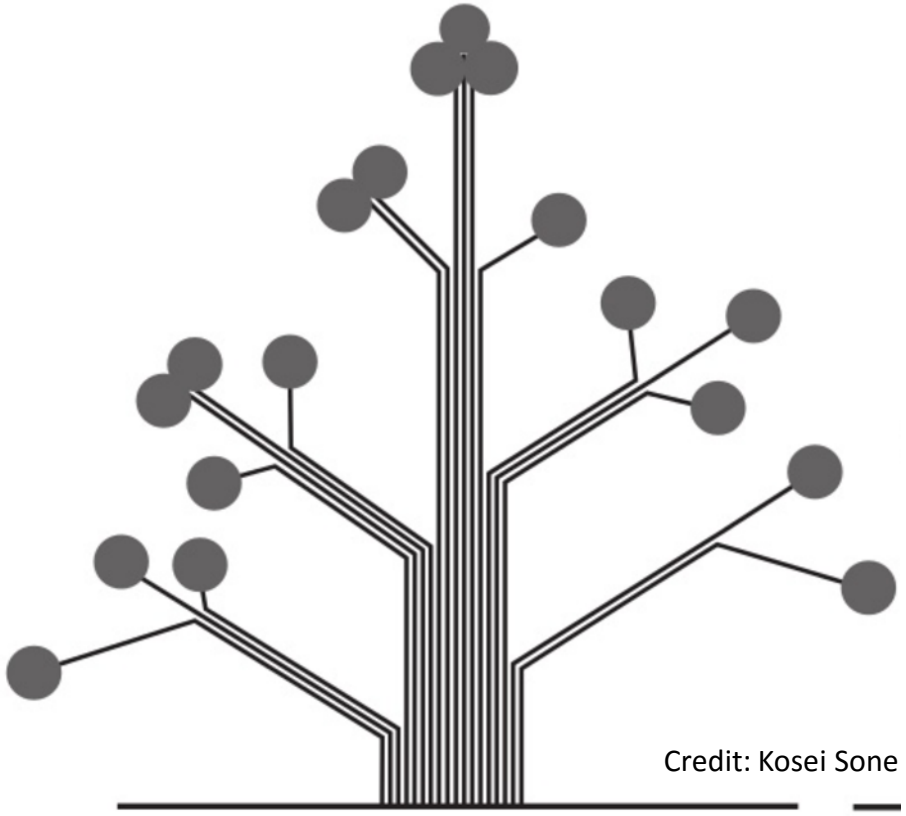
Pitfalls of the TPZ

- Are DBH-based TPZ a blunt instrument?
  - TPZ's help to ensure a minimum standard of care
  - Not designed for all scenarios (e.g. utilities trenching)
- Can we develop a new approach that puts decision making in the hands of arborists?



A New Approach

- New approach is based on the Pipe Model Theory
- Pipe Model Theory – the total cross sectional area of branches at a given point is equivalent to the cross sectional area of the trunk
- Applied to roots → The total cross sectional area of roots at a given distance from the trunk is equivalent to the cross sectional area of the trunk



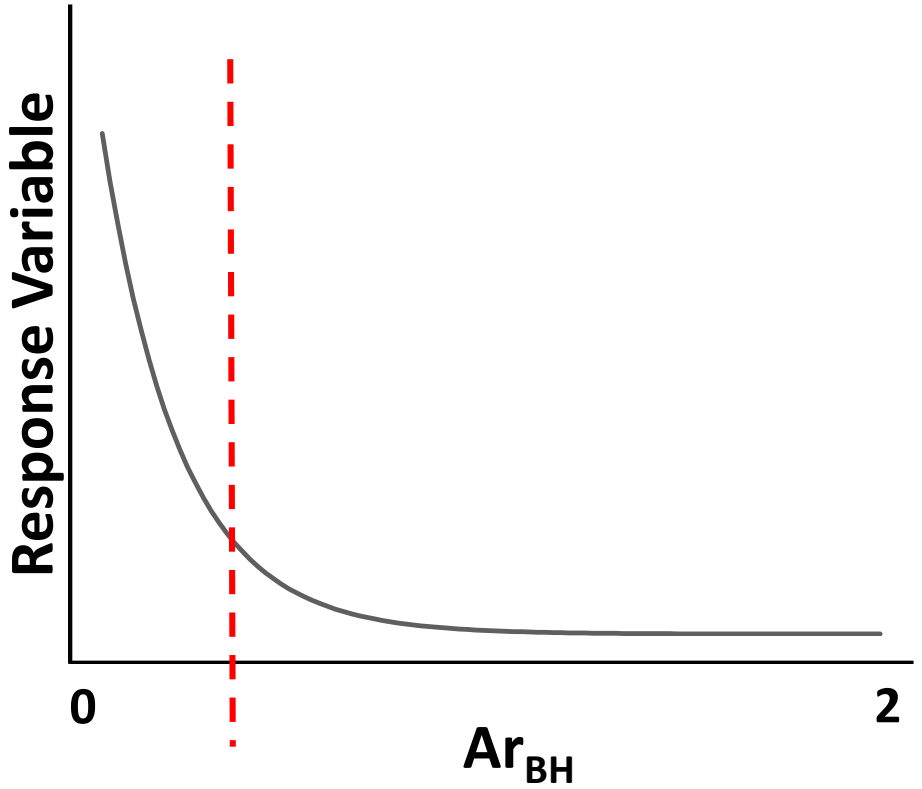
Credit: Kosei Sone

Shinozaki, K., Yoda, K., Hozumi, K., & Kira, T. (1964). A quantitative analysis of plant form-the pipe model theory: I. Basic analyses. *Japanese Journal of ecology*, *14*(3), 97-105.

A New Approach

- Use the ratio of total root cross sectional area to trunk cross sectional area (Ar_{BH}) to inform root severance decisions
  - Can we cut these roots without causing significant stress?
- The hope is to identify an Ar_{BH} threshold above which root severance should not be conducted

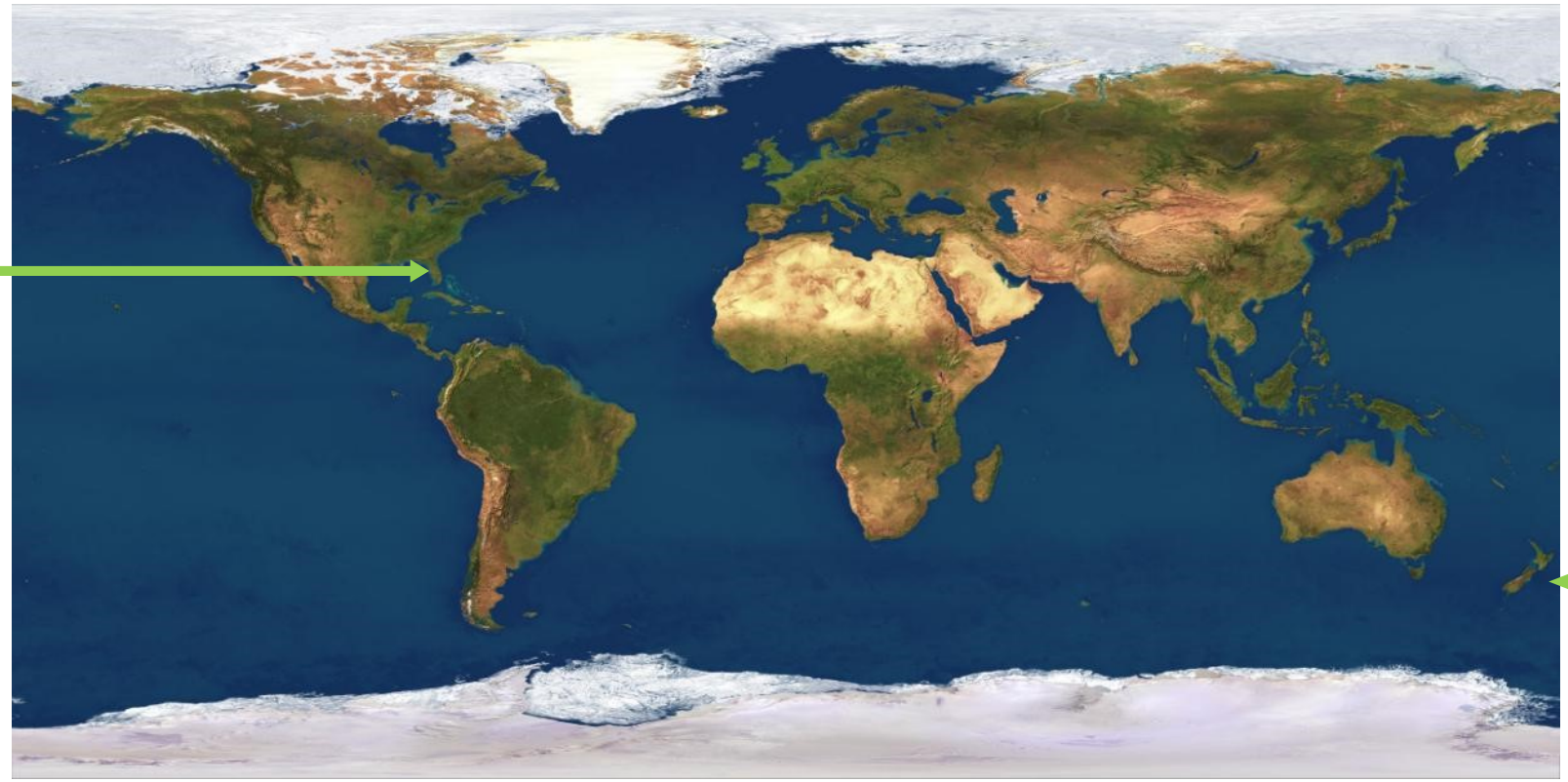
Photo credit: Deborah Howe



Research Aim

1. Measure changes in tree growth and function as a function of increasing root removal intensity
   - Root removal intensity is measured as the ratio between total root cross sectional area of severed roots and trunk cross sectional area
2. Determine if there is a critical root removal intensity above which tree function or growth is significantly impacted

Study Sites –
Florida and New Zealand



Study Sites - NZ

Trial site 1: Tāmata Maples

- 100 *Acer palmatum* ‘Bloodgood’ Thunb
- Approx. 4 m tall
- Approx. 7 cm DBH
- 2 m along rows, 4 m between rows

Trial site 2: Totara Park

- 19 *Acer negundo* **L**
- Approx. 6 m tall
- Approx. 12 cm DBH
- Linear arrangement ≈ 4 m spacing
- Four replicates of each treatment plus three controls

Methods - Root pruning treatments

- Trenches 30 cm from tree base on zero, one, two, three or four sides.
- 1.5 m long
- 50 cm deep
- Tāmata Maples: 20 replicates of each treatment plus 20 controls
- Totara Park: 4 replicates of each treatment plus three controls

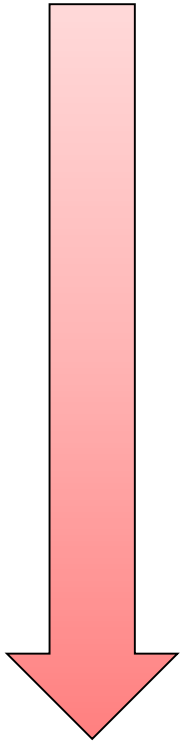
Methods - Root cross sectional area ratio

$$Root\ cross\ sectional\ area\ ratio(AR_{(BH)}) = \frac{Combined\ root\ cross\ sectional\ area}{Trunk\ cross\ sectional\ area\ at\ 1.4\ m}$$

Root cross sectional area ratio

- 0 (control) – no roots were cut
- 0.1 – 0.4 (T1) - the total RCSA is 0.1 – 0.4 times the TCSA (at DBH)
- 0.4 – 0.65 (T2) - the total RCSA is 0.4 – 0.65 times the TCSA (at DBH)
- 0.65 – 1 (T3) - the total RCSA is 0.65 –1 times the TCSA (at DBH)
- 1 – 1.8 (T4) – the total RCSA is 1 – 1.8 times the TCSA (at DBH)

Small Stress



Large Stress

Methods - Morphological response

- Relative growth rate (DBH) at 1.4 m and at ground level
  - $Relative\ growth\ rate = \frac{final\ measurement - initial\ measurement}{initial\ measurement}$
- Shoot extension (18 new terminal shoots per tree)
- Leaf area (ten sun leaves per tree)

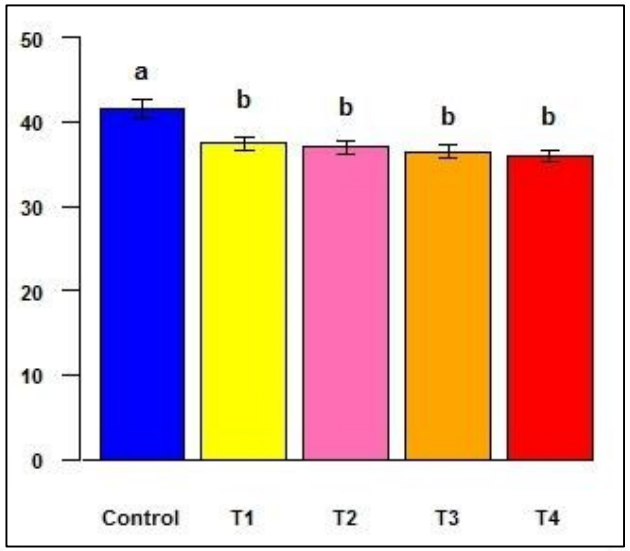
Methods - Functional response

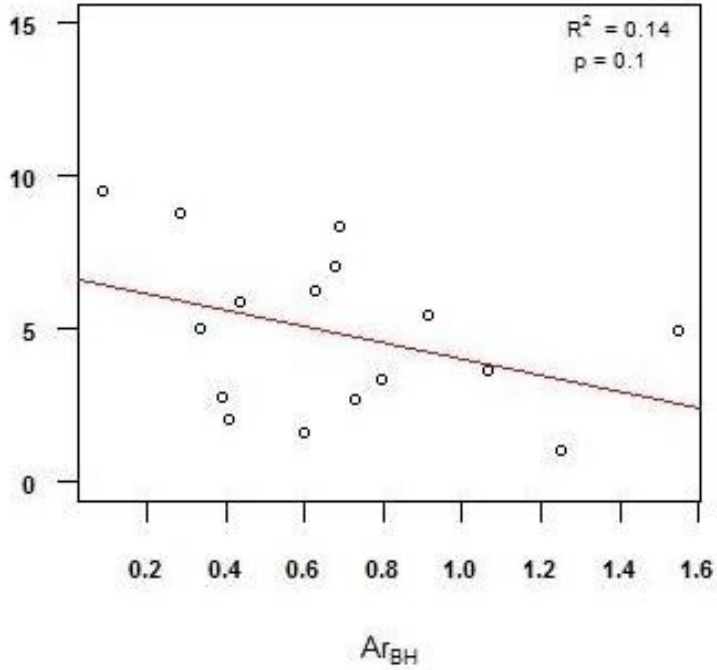
- Physiological measurements throughout the growing season (December to April) – Three fully expanded sun leaves per tree.
- Stomatal conductance
  - measure of the rate of water vapour exiting the stomata
- Chlorophyll fluorescence
  - Measure of photosynthetic efficiency

Statistical Analysis

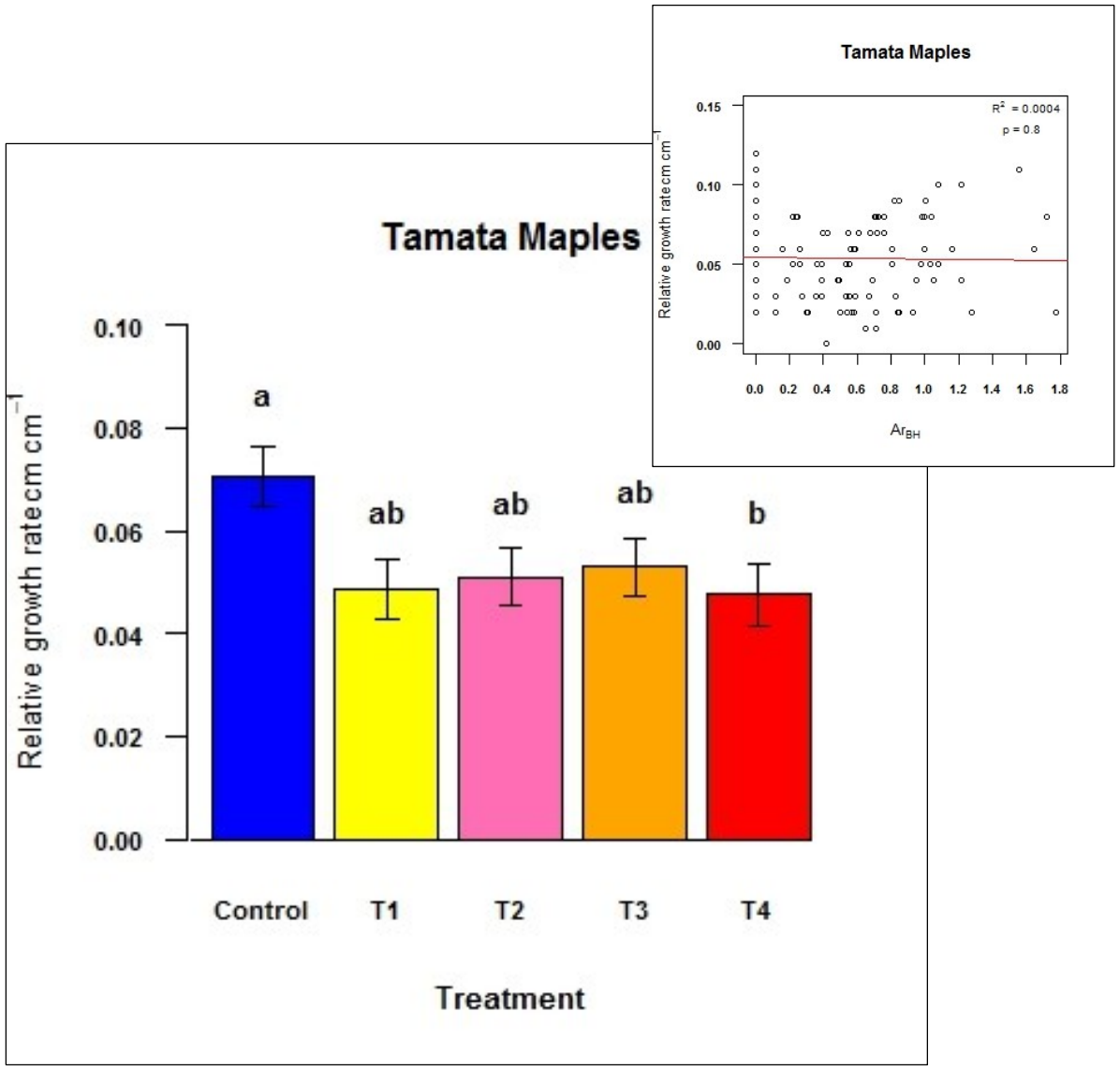
- ANOVA with post-hoc HSD tests to test whether morphological and functional responses differ significantly amongst control trees and treated trees

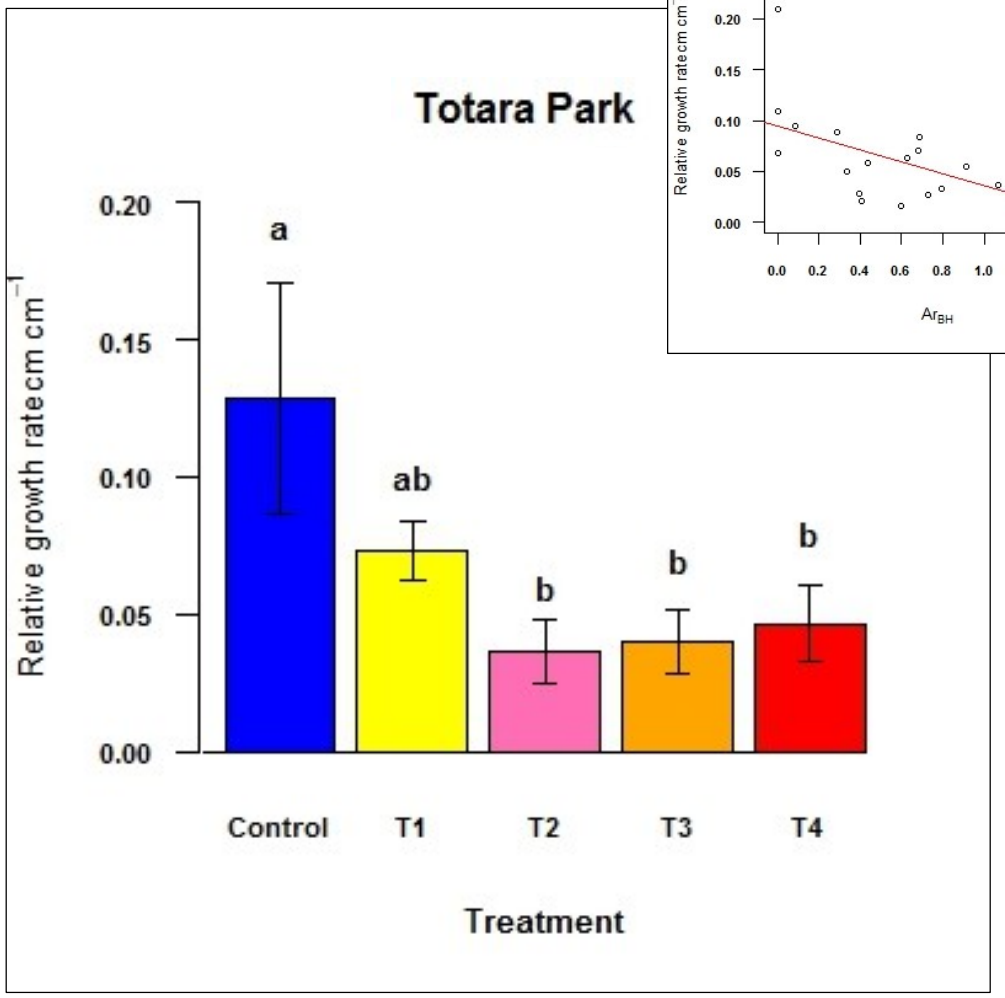
- Linear regression to investigate the effects of the continuous variable (root cross sectional area ratio) on morphological and functional response variables

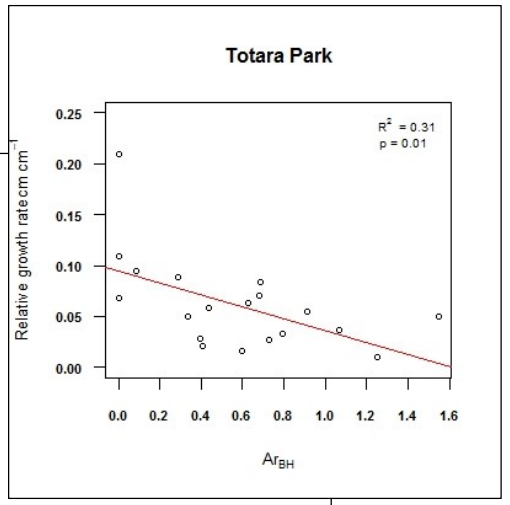




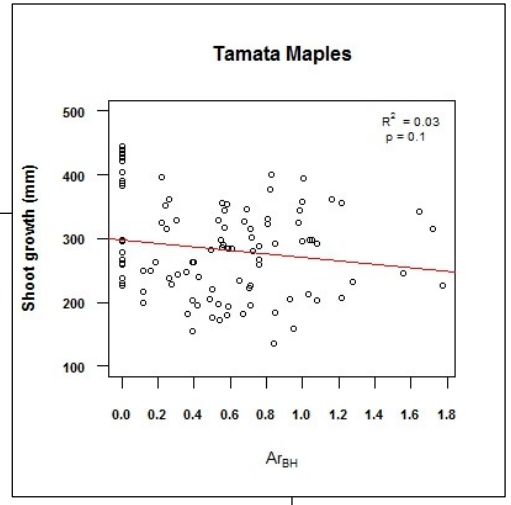
Results – DBH relative growth rate

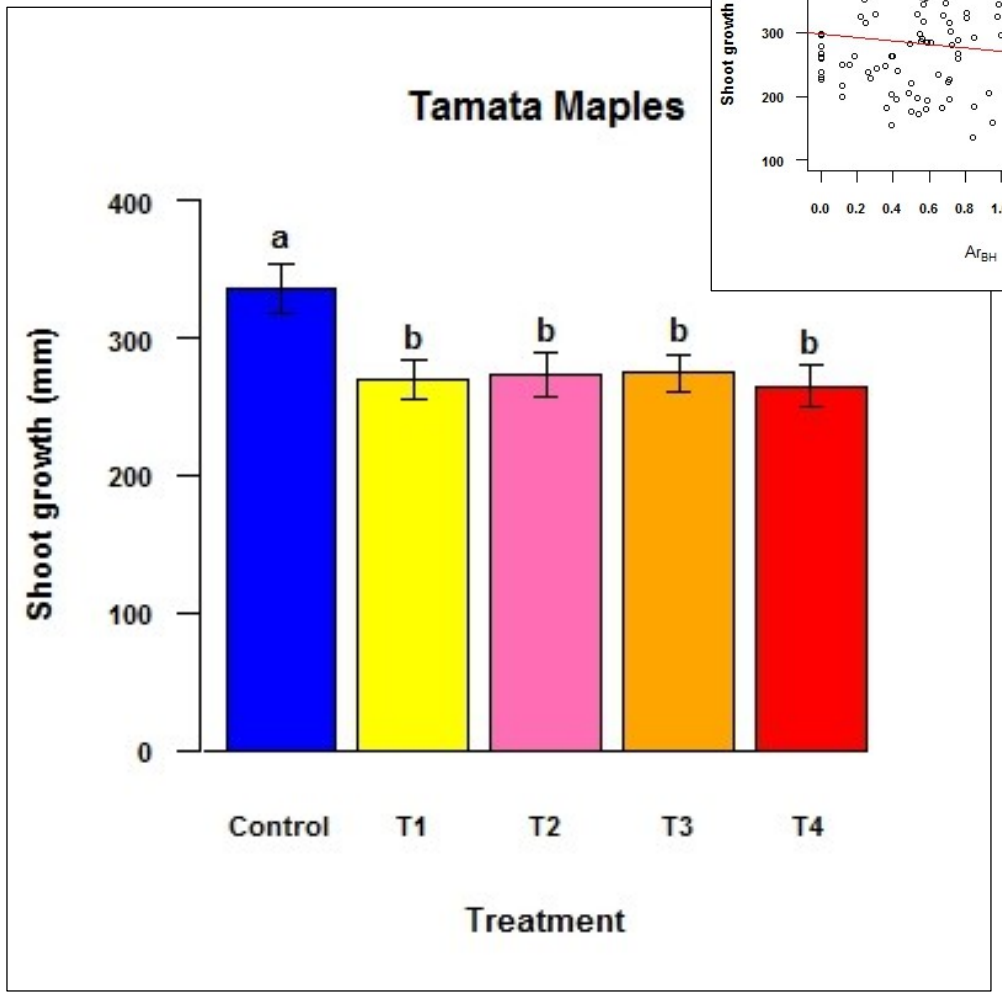


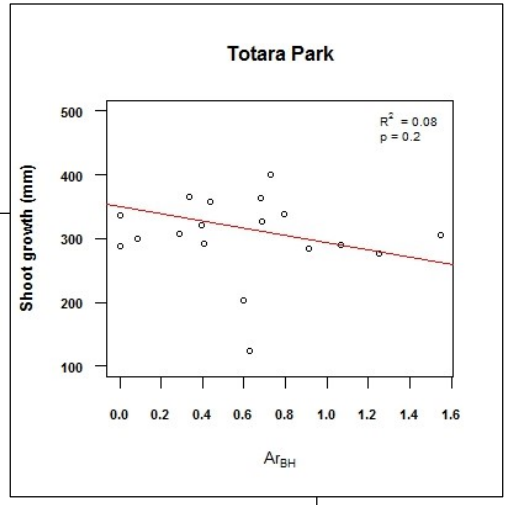


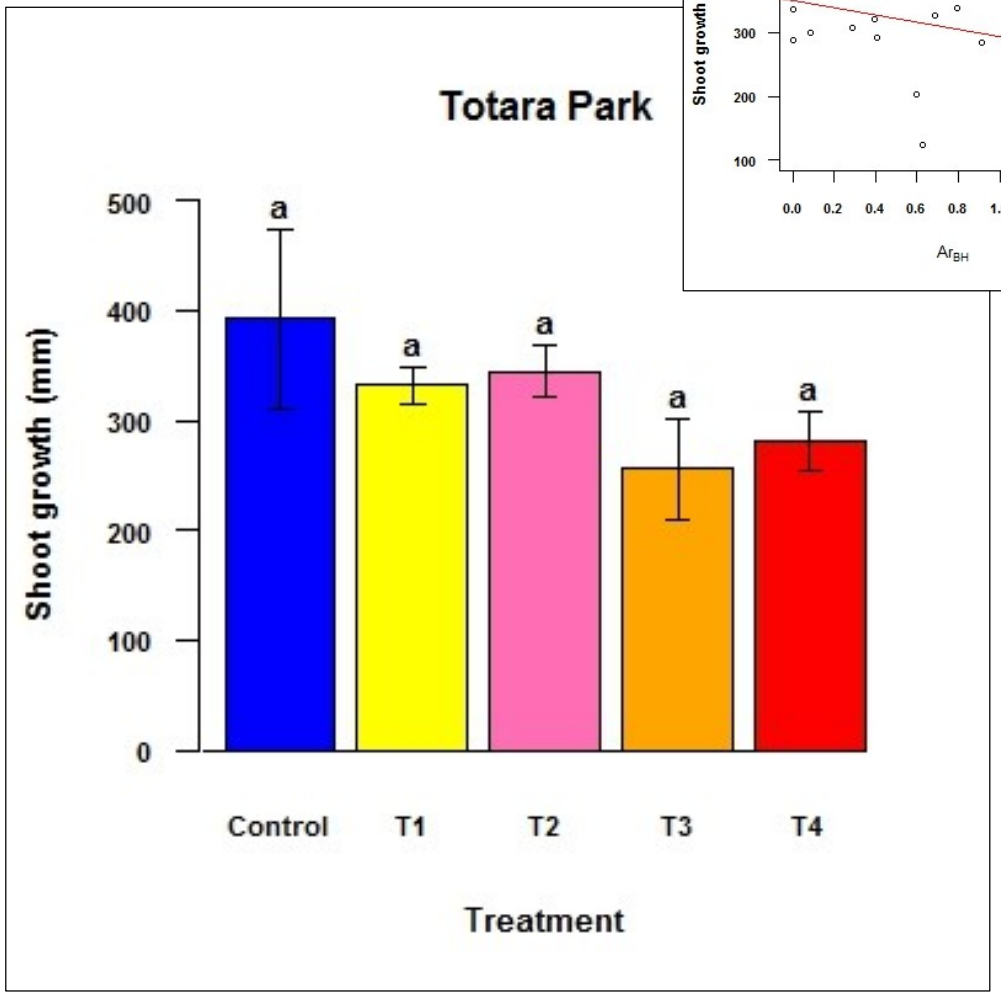


Results – Shoot Extension

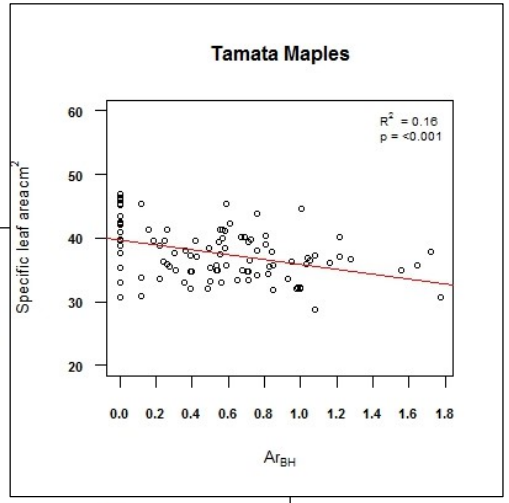


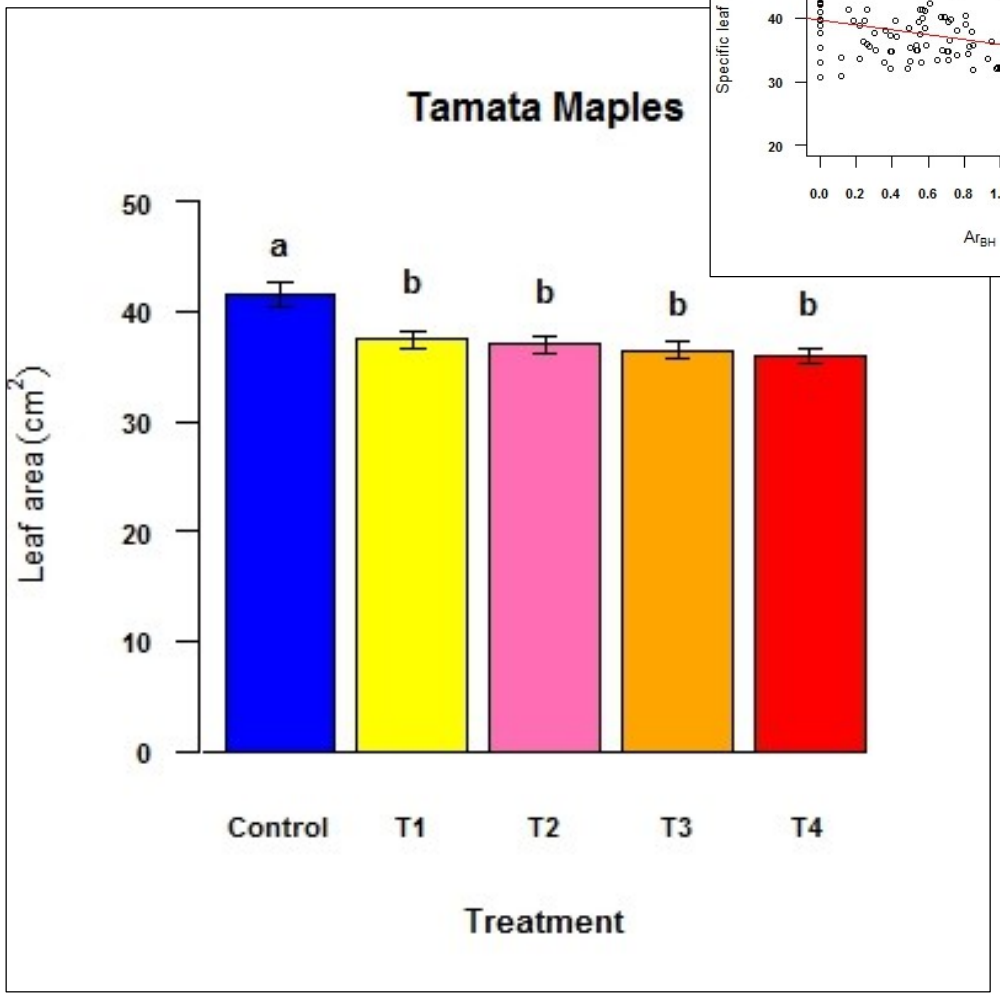


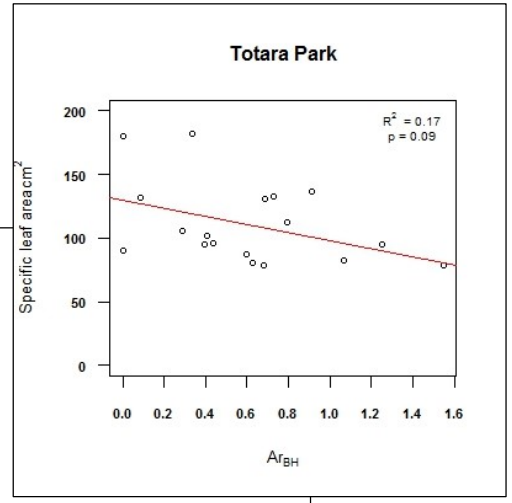


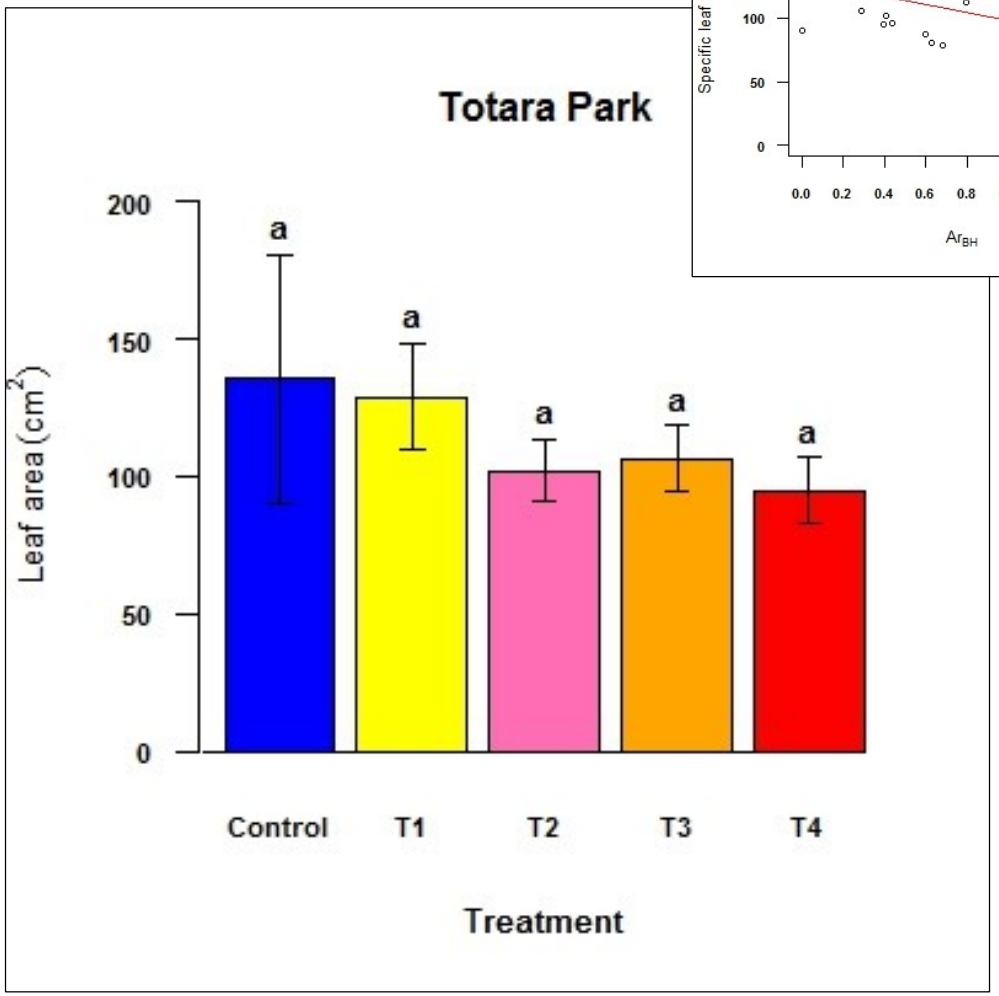


Results – Leaf Area

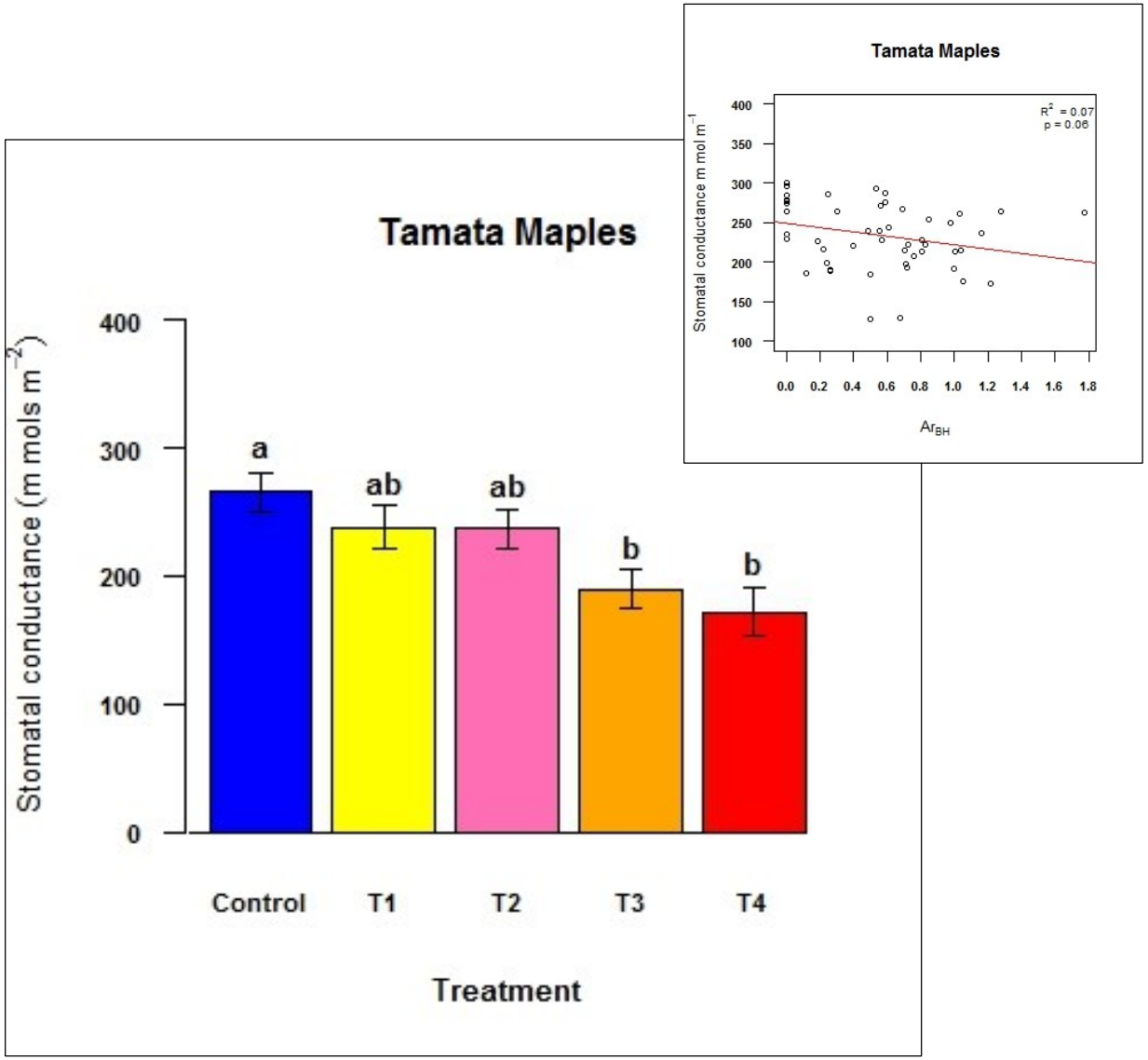


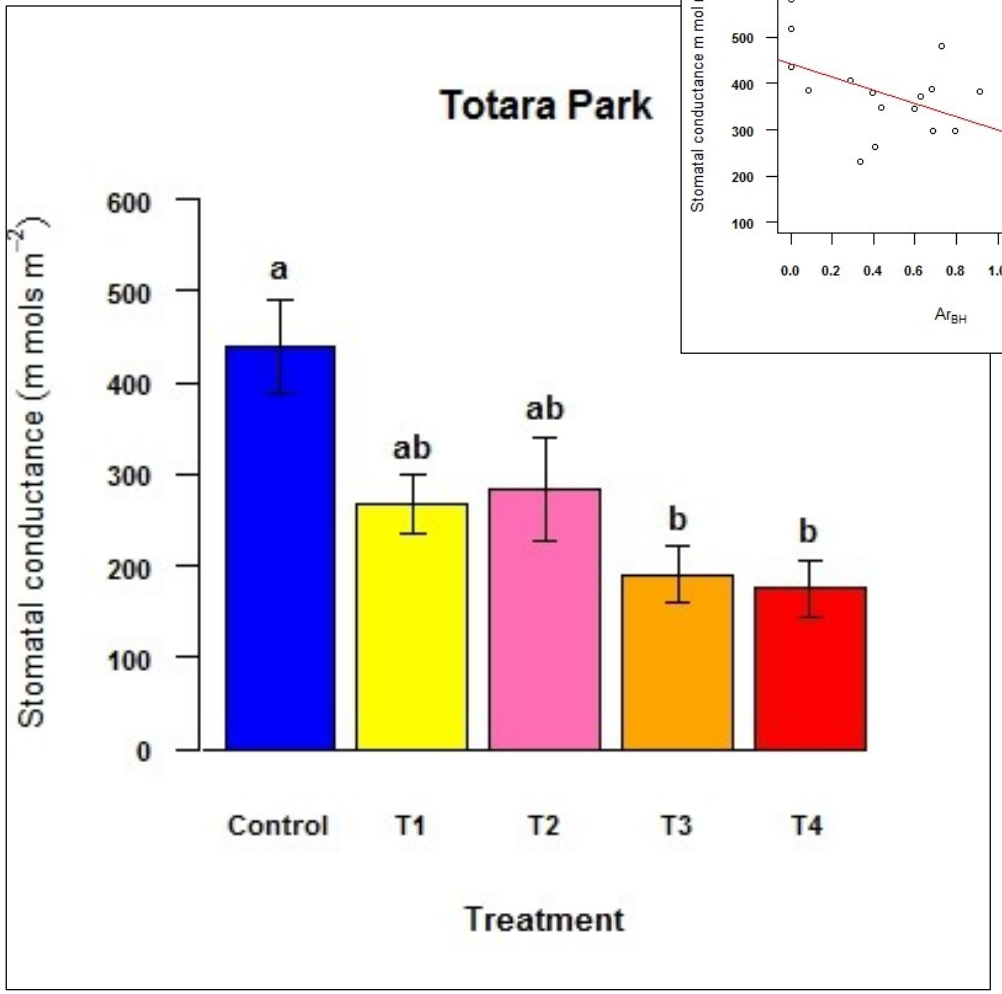


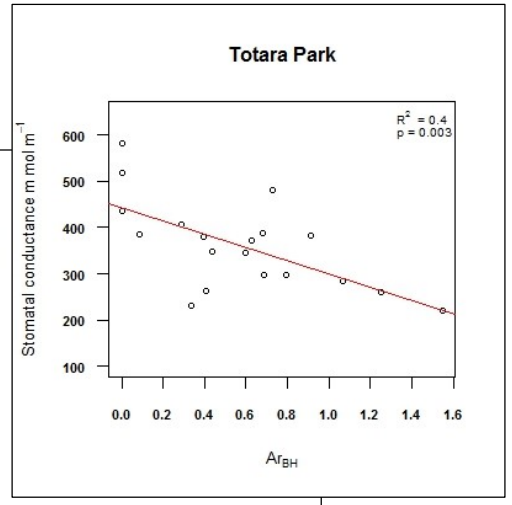




Results – Stomatal Conductance

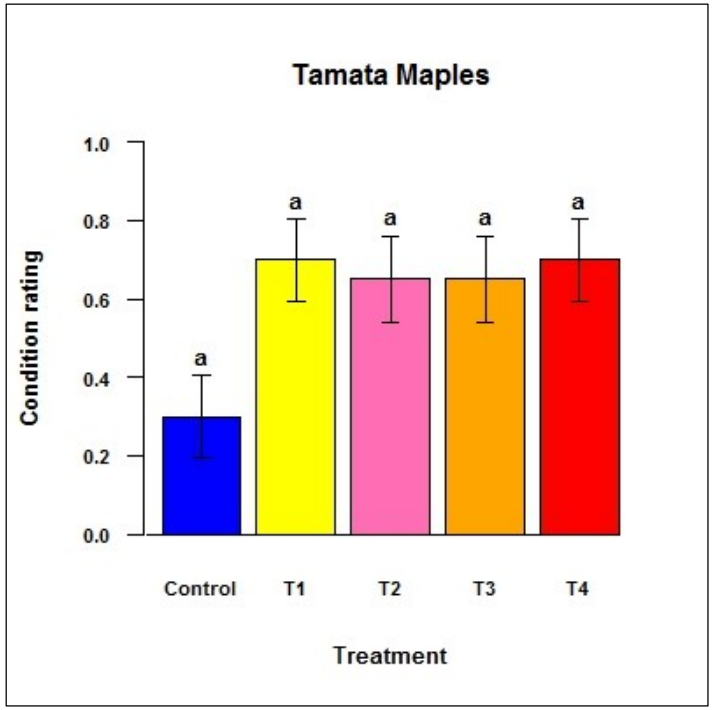


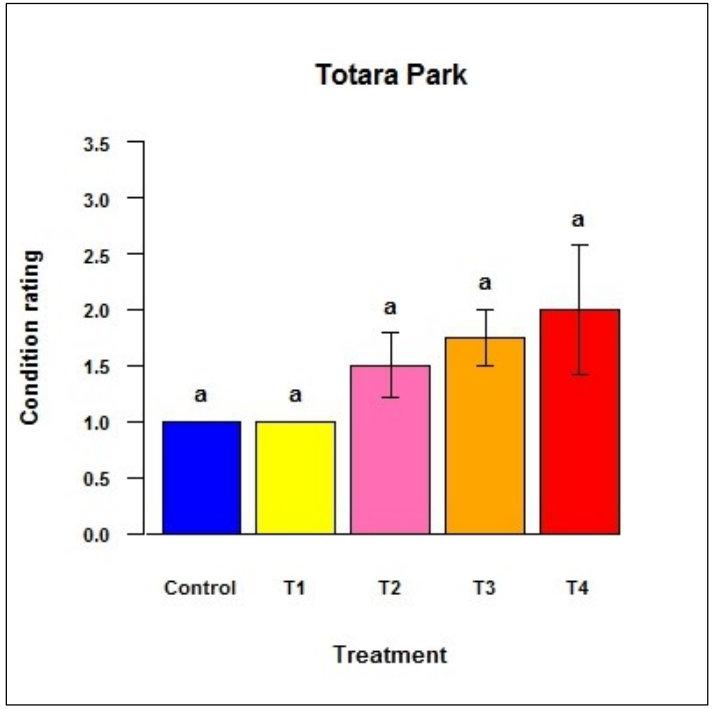




Results – Tree Condition Rating

Condition rating	Description
0	No symptoms
1	Occasional or localised defoliation. 1% < defoliation < 25%
2	Moderate but obvious defoliation. 25% < defoliation < 50%
3	Extensive defoliation. 50% < defoliation < 75%
4	Severe defoliation. 75% < defoliation < 100%
5	Complete defoliation / dead tree.





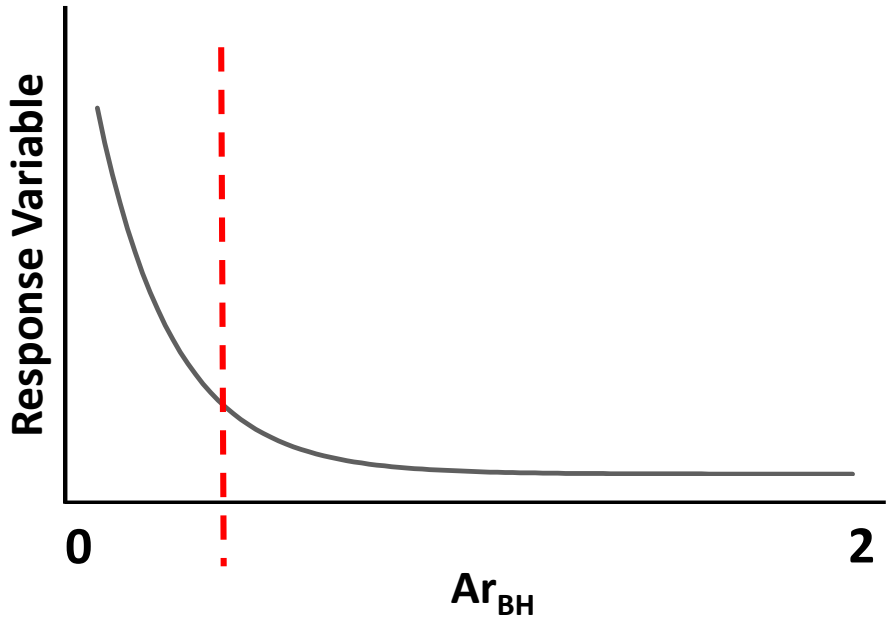
What do the results tell us?

	Did severing all roots on 1- 4 sides of the tree make a difference to the response variable?	*How many sides of the tree did we have to sever roots on to make a difference to the response variable?*	*Did the proportion of roots we severed (Ar_{BH}) make a difference to the response variable?*	*If I know Ar_{BH}, what chance do I have of predicting how the response variable will react?*
Response Variable	**Statistical Difference Among Treatments?**	**Treatment Threshold**	**Is Ar_{BH} a Significant Predictor**	**Model fit**
Shoot Extension	Yes*	≥ 1	No	Poor
Stomatal Conductance	Yes	≥ 3	Yes*	Moderate
Condition Rating	No	N/A	Yes	Moderate

* *Different species had differing responses*

Research Aims Revisited

1. Measure changes in tree growth and function as a function of increasing root removal intensity
   - *Growth and function were affected by severing all roots in as little as one trench 30 cm from the trunk*
   - *In many cases, more trenching (more root removal) led to increasingly compromised growth and function*
   - *Differences in growth and function were species specific in most cases*
2. Determine if there is a critical root removal intensity above which tree function or growth is significantly impacted
   - *No critical threshold was found…..yet.*
   - *DBH, leaf area, stomatal conductance, condition significantly decrease with increasing Ar_{BH}*



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